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NON-FERROUS METALS FABRICATING INDUSTRY: CURRENT TECHNOLOGICAL STATUS AND FUTURE PROSPECTS

A Final Report

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1. SUMMARY AND CONCLUSION

The bulk of the Canadian non-ferrous metals fabricating industry is integrated with strong indigenous companies, endowed with considerable experience and talents in engineering, marketing and finance. This vertical integration from ores to semi-fabricated products has done much to strengthen Canada's position, notably in terms of balance of payments. The health of the subject industry is naturally dependent upon several factors such as prices and demand, taxes, tariffs, transportation costs, etc. Here, technology plays a determinant role in ensuring continued growth, and in favouring further domestic integration into closer-to-finish goods (tertiary manufacturing).

Amongst the metals considered in the present study, aluminum and copper clearly present the greatest returns in terms of added values to Canadian metal commodities; paradoxically too, perhaps, they still present good opportunities for fabricating process and product improvements: this reflects market competition from cost and product quality aspects.

Technological opportunities for wrought nickel and its alloys are not as obvious, and this probably relates to the rather restricted, yet lucrative, markets for the fabricated metal in Canada, and also the strong US fabricating base.

With regard to lead and zinc, only new major markets can foster enhanced fabricating activities in Canada, and in this regard, it seems that the corresponding technological requirements would be pretty well on hand (...because of significant R&D anticipation, namely by COMINCO and NORANDA).

Finally, magnesium appears to stand out as the most promising Canadian metal commodity from the point of view of expansion of its fabricating (wrought product) prospects, with a significant export potential. Here, refining as well as fabricating costs do, indeed, present the greatest technological challenges.

PMRL/CANMET has a distinct role to play towards providing the necessary back-up to the Canadian non-ferrous metals fabricating industry. Its physical as well as human capabilities can, no doubt, augment industrial R&D efforts: it is in fact ventured that priorities will have to be established, perhaps on a basis of available expertise and know-how, with regard to the subjects (projects, programs) to be treated, etc. Suggestions for R&D topics have been formulated in this report, mainly on the basis of consultation with industry. It is further suggested that A PERSON within PMRL/CANMET be endowed with the responsibility of interfacing with the subject industry, so that both parties can come to grips with the appropriate issues, etc, in the best interest of Canada.

1. INTRODUCTION

In a recent discussion paper on Canada's mineral policy (1), mention was made of areas where direct federal efforts are particularly vital, and these included provision of adequate research and development where the private sector does not meet this need, etc. This particular aspect related to the philosophy of the referred paper (...private sector initiative with complementary government action...), whereas "opportunity" provided the theme of the paper. Furthermore, it was pointed out that with respect to Mineral Processing and Fabrication Technology, much current R&D effort at CANMET is aimed at methods to improve efficiencies in materials and energy savings in practices employed in the Canadian metals fabrication industry. Examples were given of R&D priorities, based on perceived improvements required in conservation practices, recycling efficiencies, component design and substitution methods.

In conformity with the contractor's mandate, this report attempts to give an account of (a) Canada's wrought non-ferrous metals industry, (b) current technologies and problems, (c) future technological prospects and (d) opportunities for enhanced federal R&D (specifically within CANMET).

It is necessary to add that because of budget and time constraints, limits in terms of scope and depth had to be set. For instance, the foundry industry has been left aside, and so have the processes and products related to aeronautical applications (eg. powder metallurgy techniques, hot forging and special alloys) which, on the one hand, are more in the realms of the National Aeronautical Establishment of the National Research Council Canada, and, on the other hand, do not require so forcefully CANMET's aim expressed in reference (1): i.e. improved efficiencies in materials and energy savings, etc. This applies also to nuclear applications.

In attempting to address future technological prospects, one is inevitably confronted with product market trends and forecasts. On the other hand, improved or new technologies are often called for as a result of business considerations (eg, plant economics such as increased capacity per dollar invested and/or output per direct labour hour), competitiveness in terms of product quality, and overall ability to meet the major forces controlling the behaviour of a particular business area, let aside environmental constraints, etc.

This report attempts in a very modest way to shed some light on current and foreseable technological needs in the Canadian non-ferrous metals fabricating industry, so as to justify some adjustments in CANMET's relevant R&D priorities and/or increased efforts in support of industry, on the basis of per-

ceived opportunities (theme of reference 1).

The metals which are covered in this report are: aluminum, copper, magnesium, nickel, lead and zinc. Other metals produced in Canada (cadmium, columbium (niobium), gold, indium, molybdenum, selenium, silver, tellurium, etc) do not lend themselves to wrought production in Canada, and even little, world wide. Also, uranium and zirconium alloy fabrication has been left aside since it was tacitly agreed, at the outset, that these materials are thouroughly covered by other governmental agencies, namely, Eldorado Nuclear, Defence Research Establishments (e.g., DREV), on the one hand, and Atomic Energy of Canada Ltd (Chalk River Nuclear Laboratories, in particular) on the other hand. In the latter instance, it is worth recalling that NORANDA's Special Metals Division, in Arnprior, Ontario, phased out, a few years ago, from its zirconium alloy (...fuel sheathing and pressure tubing...) fabricating operations!

2. CANADA'S WROUGHT NON-FERROUS METALS INDUSTRY

(A) General

The subject industry can be defined in the following terms, using Simmonds' terminology (2): (a) its business area relates to (i) industrial goods and services (basic metals and shapes) and (ii) to consumer products (autos, metal shapes, hardware, packaging); (b) its business aims are, respectively, (i) cost-minimizing and (ii) sales-maximizing; (c) its profit loss is due to business cycle in either case; (d) the major forces for change are driven, respectively, by (i) population and economic growth, and (ii) higher living standards; (e) major forces controlling industry behaviour are respectively (i) standardized technology, products to international specifications, major changes at irregular intervals, problems with capital accumulation, international competion, and (ii) consumer's disposable income, finite markets (changing needs/wants), balance of prestige, fashion, utility, convenience, etc, high development, market entry costs, competition between products and industries.

A third manufacturing business area, namely, high technology, aiming at performance-maximizing, etc, is but a small fraction of Canada's wrought non-ferrous metals industry (e.g. aerospace, nuclear, electronics, etc). This area will not be treated here.

Canada's non-ferrous metals fabricating industry is based on a strong indigenous mining, smelting and refining industry. Deeks (16), in 1977, summarized Canada's position in this regard, under the theme of Canadian Minerals in Global Perspective: "...Canada is the world's third-largest producer of mine and mineral products, after the United States and Russia. Canada is the world's largest producer of nickel, asbestos, zinc, selenium and tellurium; second in molybdenum; third in copper, lead, gold and silver; and a major factor in iron ore, potash, uranium and many less significant metals such as platinum, palladium, bismuth and cadmium. About 30% of our copper, 10% of our zinc, 15% of our lead and 4% of our nickel are processed through the end-use manufacture in Canada. Most of our nickel, 75% of our copper and half of our lead and zinc are processed to primary metal in Canada. We mine 12½% of the world's copper, 28% of its zinc and 15% of its lead, etc...". Deeks went on to dissertate on manufacturing operations, and his review, overall, is worth reading and still very much à propos!

(B) Aluminum

Aluminum is the world's most widely used non-ferrous metal: it ranks second only to iron and steel in the metals market. Its usage continues to grow in sectors such as transportation, food containers/packaging and building and construction.

Canada's production of primary metal was 860 286 tons in 1979 (3). Last year (1981), Alcan's smelters alone produced 962 100 tons of primary aluminum. From this, 225 000 tons of fabricated products were purchased by Canadian users (4).

Primary aluminum and semi-fabricated products are produced in Canada by two companies: Aluminum Company of Canada, Ltd (Alcan), with some forty production facilities and 20 000 employees spread through-out the country (4), and Société Canadienne de Métaux Reynolds, Ltée, with refinery in Baie-Comeau, Québec, and fabricating facilities in Québec and Ontario, with an overall human resource of some 3 000 people.

The flat-product segment of the industry is essentially with the producers, whereas the aluminum extrusion business is divided amongst:(a) producers (Alcan, Reynolds, Kayser), (b) diversified industry, eg, INDALEX, and (c) independant extruders, eg, ZIMMCOR, etc. Aluminum extrusion is flexible (typically small outputs of greatly varied shapes and geometries) and it lends itself readily to new products of complex design.

A good review of present aluminum applications and of the responses of the industry to its problem areas has been made by Ballance (see chapter 6 (B) (iii)); it focuses in particular on food containers, and electrical and automotive applications, on the one hand, and on recycling, ore supplies and energy consumption, on the other. These highlights (...of the US scene...) are accompanied by an outline of the voice of this industry, namely, the Aluminum Association.

Here in Canada, probably only Alcan can take leadership or initiative in response to process and product pressures and forces for change (...because of its size - both in terms of production capacity and R&D capabilities...). Alcan clearly follows set patterns or trends, but it can innovate in many respects in order to increase its competitiveness on world markets. Obviously, Canada's cost advantage in electrical energy will continue to sustain the industry's competitive position as offshore electrical power and petroleum costs continue to rise. As a result, the rate of growth in Canadian primary aluminum production capacity should continue to at least equal the growth rate in total world capacity (3). The crux, however, will remain "exportability" of semi-fabricated/fabricated (finished) products (eg, extrusion profiles), parti-

larly when one considers (in the latter case, eg, extrusion) a ratio of some forty extrusion presses in Canada versus about four hundred and seventy presses in the US (24).

On the ground of limited domestic consumption, aluminum product development in Canada has, sofar, been focused on large market potential amenable to sizeable export: the technological trend, therefore, has been geared to flat product or rod and/or wire for electrical applications.

(c) Copper

In 1979, production of copper in Canada was 643 754 tons with a value of $1 515 443 000 (3).

In 1981, copper and copper alloys produced in Canada could be divided as follows (5):

(a) wrought products		
- electrical (rod, wire)	178 622 tons	96%
- brass mill (sheet, strip, tube)	89 532 tons	
(b) cast products	10 250 tons	4%
- 50% sand cast		
- 20% cast by other means		
- 30% plumbing products		
TOTAL (copper content)	278 404 tons	100%

Wrought copper producers can be divided as follows:

(a) electrical rod, wire (and cable)-essentially pure copper

- Canada Wire and Cable Ltd (with plants in Montreal, Toronto, Fergus, Simcoe)
- Cable Tech Company Ltd (with plant in Stouffville, Ont.)
- Northern Telecom Canada Ltd (with plant in Montreal)
- Phillips Cables Ltd (with plant in Brockville, Ont.)
- Pirelli Cables Ltd (with plant in St. Jean, Qué.)

(b) <u>brass mill rod, sheet, strip, tubing (seamless)</u>

- Noranda Metal Industries Ltd (with plants in Montreal, Arnprior, Fergus, New-Westminster, and Newtown, Conn, USA)

(c) <u>brass mill rod, sheet and strip</u>

- Arrow Head Metals Ltd (with plant in Toronto)

(d) <u>brass mill sheet and strip</u>

- Ratcliffs Canada Ltd (with plant in Richmond Hill, Ont.)

(e) <u>brass mill tube and pipe</u>

- Wolverine Division, UOP Ltd (with plant in London, Ont.)

Briefly, the Canadian copper industry continues to pursue aggressively (under the impulse of its American counterpart...) reconquering (...of apparently lost markets...) and conquering new markets, such as solar heating and, more recently, aqua-culture applications (cupro-nickel), fire-protection devices including sprinklers (...from the steel or cast-iron product), the reviving market being roofing applications.

(D) Lead

In 1979, production of lead in Canada was 315 751 tons with a value of $ 414 416 000 (3). Major producers are Cominco Ltd and Noranda Mines Ltd, both with mining, smelting and refining capabilities.

The major markets for the metal are lead acid batteries, solder for metals joining, fabricated products (essentially plate, sheet, strip, pipe and tubing), and oxide and chemicals. In the past ten years, the consumption of wrought lead and lead alloys (fabricated products) has declined over 100 000 tons or from 28 percent to 17 percent of total reported lead consumption (6). The key industries that utilizes fabricated lead products are: construction, automotive and chemical processing. End-use applications therein include: radiation and x-ray shielding, nuclear shielding in maintenance areas, storage and transportation of radioactive wastes, noise control, architectural (waterproofing, roofing, flashing and ornamental) applications.

Amongst Canadian lead producers, only Cominco has interests in fabricating operations (50 percent ownership of the Canada Metal Company Ltd). The latter produces lead sheet for sound attenuation applications, and rolled product for architectural uses. It also extrudes lead-tin type soldering wire as a major product.

(E) Magnesium

In 1979, production of magnesium in Canada was 9 172 tons with a value of $25 073 000 (3). Canada's only producer of magnesium metal is Chromasco Ltd, with mine, smelter and fabrication in Haley, Ontario. The company's rated annual production capacity is 12 000 tons. Chromasco Ltd currently operates 3 shifts per day, 7 days per week, with a task force of some 430-450 people. About half of the metal production is exported, the remainder being consumed domestically (including the US). The only wrought products are extrusions of various shapes, sizes and alloys, and these account for only about 10-15% of total metal production.

(F) Nickel

In 1979, production of nickel in Canada was 131 579 tons with a value of $826 400 000 (3). Three companies dominates the scene, with INCO Ltd (with three refineries), Sherritt Gordon Mines Ltd (with one refinery) and Falcombridge Nickel Co. Ltd, as an important mining company.

Domestic as well as exported nickel consumptions are mainly as an aloying element primarily to stainless steels, and to a lesser extent, to copper. In the fabricating (wrought products) area, significant operations exist within INCO (its Canadian Alloys Division, near Sudbury, concerned with the fabrication of coinage strip by powder metallurgy), also within Sherritt Gordon (dispersion-strengthed nickel...), within Associated Tube Ind. (Toronto) and within Noranda's new NORSAND Metals division (...a recent Noranda/Sandvik joint venture) in the fabrication of high-nickel alloy tubing.

(G) Zinc

In 1979, production of zinc in Canada was 1 148 498 tons with a value of $1 107 419. Lewis (7) in 1978, has given a good resumé of current status and supply/demand outlook. In his analysis, he brushed the following picture: "... zinc has sometimes been called the unknown metal. Considering that on a world basis it ranks third amongst non-ferrous metals in production and consumption, zinc retains a certain modesty. It has no distinctive colour like copper, lacks the low density of aluminum and magnesium and is not always easy to identify as a product. The "spangle" of galvanized steel is probably zinc's most distinguishing feature".

Lewis also alluded to the fact that only about 7% of western world uses for zinc goes into wrought (particularly rolled) products, this being in sharp contrast to copper and aluminum, and suggests an obvious target for new product development. That very point has been, indeed, the subject of individual efforts from zinc producers, particularly in Europe and North America, notably during the 60's and 70's. Unfortunately, little commercial success came about. In retrospect, however, it is interesting to notethat much of that effort has opened up major new applications, namely, foundry products, which are currently threathening ferrous and non-ferrous parts for a host of applications.

Zinc and zinc alloy fabrication in Canada is practically non-existant, with the exception of a captive battery slug operation within Union Carbide (Toronto), and a small forging capability within Cominco.

In the USA, a recent marketing breakthrough came about for wrought zinc: copper-plated zinc coinage (pennies). This event opened up a brand new market for rolled zinc , estimated at 40 000 tons per year in the USA and with good potential for growth in other countries, including Canada. According to a Noranda spokesman (19), this could represent a Canadian market of about 8 000 tons per year; clearly, other rolled product applications would be required in order to justify the associated continuous strip casting and rolling facilities.

3. CURRENT TECHNOLOGICAL STATUS

(A) General

Major North American technological developments that emerged during the last 25 or 30 years, and which were directed at some of the non-ferrous metals fabricating industries, centered essentially on semi-continuous and continuous operations. These were typified by casting and annealing processes. For various reasons, Canada was slow at adopting some of these new developments: high capital costs, large production outputs, lack of flexibility in terms of "alloy mix", were amongst the major reasons for this resistance to change. On the other hand, increasing pressure from customers for improved quality, large unit coils (without welds), etc, enticed some Canadian companies to yield some of the pressure.

(B) Aluminum

The Canadian aluminum industry was the first to introduce semi-continuous casting of rolling ingots and extrusion billets, and fully continous casting of strip. Alcan's Shawinigan plant in Quebec installed the first Canadian Hazelett strip casting process in the mid-50's. Billets and ingot semi-continous casting equipment were also installed by Alcan and by Reynolds in Eastern Quebec in the late 50's and early 60's.

Since then, new rod mill capabilities were installed by Alcan in 1981, in Vancouver, BC. Commissioning of the new 84-in. wide Alcan continuous caster at the Rolled Products Division's Saguenay Works, in Jonquière, Quebec, was initiated during the second half of 1981. Successful production trials have been completed for aluminum coiled sheet for the building and construction industry. Development work continues on the casting of a range of hard alloys. North American demand for these products exceeds 1 million tons per annum. Development work was completed on a new product - reflectorized sheet - and the first commercial order was obtained from the Quebec government for the manufacture of licence plates. During 1982, the Extrusion Division will be involved in several projects which include the start-up of a highly automated third press at Laval Works, in Laval, Quebec.

Reynolds Aluminum Ltd, with its refinery in Baie Comeau, its flat product (rolling) operation in Cap-de-la-Madeleine, Quebec, and its two extrusion plants in Quebec and Ontario, follows as a good second citizen: its most recent development relates to a system for shape and gage control of cold rolled aluminum ("Sheetforme" - 1600 System) (8). Reynolds' overall operations utilize current technologies of its aluminum fabricating competitors: semi-continuous and fully continuous casting processes being a commom denominator.

(c) Copper

In the copper and brass mill industry, Noranda Metal Industries Ltd was the first Canadian producer to install continuous strip casting equipment in the mid-70's, at its Fergus plant, in Ontario. It now operates four horizontal units, including two Technica-Guss machines, in the production of a variety of alloys.

More recently (21), Canada Wire and Cable Ltd (a Noranda wholly-owned subsidiary) has embarked on the installation of a continuous cast copper rod mill, adjacent to their conventional copper rod rolling mill, in Montreal-East, Quebec. This became a necessity in view of growing competition for improved quality product, particularly fine magnet wire. The company opted for the Contirod process (Hazelett belt caster and associated Krupp rolling mill) as experienced very successfully by Metallurgie-Hoboken in Olen, Belgium, many years ago.

Moreover, Canadian Copper Refiners, in Montreal-East, Quebec, is currently commissioning a vertical (Krupp design and Asarco mould) semi-continuous casting machine, which had been mothballed for several years. Part of the copper billet production will feed Noranda Metal Industries' extrusion presses (in Montreal-East) for the fabrication of (a) thin-wall copper tubing, and (b) special shapes for electrical applications.

It is also worth recording that Kidd Creek Mines Ltd in Timmins, Northern Ontario, have recently (1981) started one of North America's most technologically advanced copper smelting and refining facilities (22): they are the first plant in North America to use a Hazelett continuous casting machine for the commercial production of copper anodes. This replaces the wheel-mounted mold casting used in more conventional smelters.

The advent of superior quality copper billet production within Noranda will callfor improvements of the extrusion operation: in this regard, no drastic changes have occured yet, with the exception of water-quenching at the press which has recently been adopted successfully (...lagging of course significantly with respect to the aluminum industry...) as a measure of controlling grain size, particularly with regard to smooth, thin-wall, tubing during subsequent cold-processing (drawing) operations.

Tubing with enhanced surfaces (for heat-transfer applications), a concept which was introduced in the US, namely by Dr. French, and which was capitalized upon by Noranda in the early-70's, is still a significant Canadian "trump card": Noranda's Forge-Fin Division, in Newtown, Connecticut, has made sizeable headways in this competitive field. Recent trends, from a processing point of view, seem to point towards a quieter process, that is from

forging to straight drawing (with a rotating die), for the spiralling internal fin configurations.

In summary, it can be said that notable modernization has taken place in the recent past within the Canadian copper and copper alloy fabrication industry. Also, some producers have opted for specialization and alloy rationalization (fewer alloys), eg, Noranda's complex copper extrusions, Ratcliffs' major thrust on thin strip for automotive applications, Wolverine's continued strive for water and condenser tubing: Arrow-Head Metals is probably the only generalist, but it has its place on the Canadian scene!

(D) Lead

In parallel with producers' in-house capabilities, the International Lead Zinc Research Organization, Inc (ILZRO) manages the cooperative research and development effort on behalf of its supporting members - lead, zinc and cadmium miners, smelters, and refiners - throughout the world (see for instance, references 17 and 18). Individual research projects are carried out on a contract basis at university, governmental, industrial, or private laboratories throughout the world. Contractors are selected on the basis of their capability in the particular area of proposed R&D. Although emphasis is on applied research, ILZRO also carries out a significant number of fundamental projects, many of them through fellowships.

Examples of wrought lead technologies that resulted (totally or in part) from ILZRO's projects include: "Lead Powder Metallurgy", "Continuous Extrusion of Cable Sheathing", "Lead for Sound Attenuation", "Powder Roll Cladding of Lead to Steel", "Development of the Continuous Sheet Lead Casting Process", etc.

In Canada, lead fabrication technology is adequate for the present markets, and it lies pretty well with COMINCO.

(E) Magnesium

At Chromasco Ltd (9), the metal obtained in the last stage of the reduction process (the Pidgeon Ferrosilicon Process) is melted in seven, 5 000 lb steel crucible, natural gas fired, furnaces. Molten magnesium is pumped to the various casting stations, where it is protected against oxidation by an atmosphere of sulphur hexafluoride and carbon dioxide.

Extrusion billets, ranging in diameter from typically 5 to 8 inches, are produced by the DC (Direct Chill) semi-continuous casting process. After being machined all over, the billets are induction pre-heated, and extruded in either a 2 400 ton or a 500 ton hydraulic press. Standard extrusions such as angles, channels and tubes are produced in many sizes (1/8 to 4 1/2 in. rods, and 1 by 1 3/4 bars, for instance). Production of exclusive shapes for specific products include: ladders, luggage frames, dockboards and diamond drill rods. Anodes for the cathodic protection of hot water tanks, for example, are fabricated from magnesium rod extruded successively in the two presses. The present maximum extrusion output is about 1 ton/hr.

An electrically heated batch annealing furnace is used to confer special mechanical properties to certain alloys (10).

The reader is referred to an excellent review paper by Fisher (11) for a comprehensive summary of production, properties and use of magnesium and its alloys.

(F) Nickel

Significant wrought nickel technologies in Canada center essentially on strip and tubing. In the former case, the market is coinage strip for the Canadian Mint, and the producers (INCO and Sherritt Gordon) employ proprietary developments based on powder metallurgy techniques (...atomization, compacting by rolling, sintering, etc...). In the latter case, high-nickel alloys are produced by Noranda's Special Metals Division (now Nor-Sand Metals Inc - a Noranda/Sandvik Joint Venture - in Arnprior, Ont.) by the pilgering (incremental deformation) process, etc. On the other hand, welded tubing is produced by Associated Tube Ind. in Toronto.

(G) Zinc

A significant amount of know-how has been developed in Canada over the last 15-20 years on the fabrication and properties of zinc and zinc alloys. Cominco's Product Research Centre and Noranda Research Centre have complemented their efforts to bring new dimensions to this "modest" metal. Chollet (12,13) has summarized some of the ensuing developments which, unfortunately, have not quite materialized.

World-wide, there is continuous strip casting capacity (Hazelett process) in excess of the demand for rolled zinc and zinc-titanium type alloys. Semi-continuous billet casting of the referred alloys as well as of improved (near-eutectoid zinc-aluminum) compositions has been successfully demonstrated on a commercial-scale basis, and experimental extrusion, drawing, as well as rolling schedules have been developed on a large scale. Forging technologies have also been mastered, and the technical feasibility of rod casting has been demonstrated. Coating techniques have also been studied, and novel market applications (screw-machining, superplastic thermoforming, etc) have been thoroughly examined.

Thus, in retrospect, something seems to have been missing

in the aforesaid developments: perhaps a conjecture of some kind, related to a combination of factors such as price, properties, adequate production facilities, or timing ...for successful market penetration!

4. FUTURE TECHNOLOGICAL PROSPECTS (FORECASTS OR TRENDS)

This topic requires an introduction. Perhaps the first comment concerns the time-scale. Indeed, technological forecasts, for instance, can be as short as one to five years, as practised by Metal Progress (American Society for Metals) in its January issues. The probabilistic element in forecast is not found in trends which are merely extrapolations based on past and current events. In any case, future prospects are governed by economic considerations and social-political issues (market situation, strikes, environmental constraints, etc). Furthermore, the choice, say, of a given (emerging, developing or proven) technology, depends on economics of scale (technology capability versus needs of a given company, etc).

Also, it is interesting to note that in the area of metal fabricating and manufacturing processes (and in other sectors as well), machine or equipment designers and builders are often ahead of the needs. This is also frequently the case in alloy development where technical solutions emerged which were not necessarily commercially viable.

Thus, it is felt that instead of trying to establish a time-scale for future technological prospects, it would perhaps

be much preferable to indicate needs, as expressed by industry (...and whichever forecast...), and to base opportunities for enhanced R&D on these needs, etc.

Trends, if not forecasts, in the Canadian non-ferrous metals fabricating industry, still point towards continuous operations, from casting to annealing, and this for reasons of economy (man-power, energy) and quality. However, there is here a dichotomy or a two-tier situation (14): on the one hand, massive investments and production volumes, thus very large business, and on the other hand, lower investments aiming at similar productivity and quality, but for lower production volumes, and possibly too, for greater flexibility (in terms of alloys and products) which is what Canada needs in certain instances (aluminum extrusions), with the exception perhaps of straight copper semis such as anodes, and more certainly rod & wire (copper and aluminum) for electrical applications. Thus, economies of scale will always prevail in Canada, particularly for alloys.

Still relatively non-commercialized (...and yet forecast 3 to 5 years ago as the coming event...) is hydrostatic extrusion: ASEA's Quintus press, UKAEA's hydrospin process, Conform, extroling, etc (see Appendix B). Reasons seem to relate to economics of scale, tooling problems, lack of flexibility (in

terms of range of alloys), productivity, etc. These processes will find their "niche" in due course, but they are simply not suited for large-volume productions. This applies equally well to rod (or generally, thin section) casting of alloys. As pointed out by a Noranda spokesman (15),these efforts, such as BATTELLE's group sponsored research on the "Hydra-film" process, have yielded at least an awareness of the importance of lubrication and tooling (design, life, etc) towards the commercial objective of long billets (large unit weights)!

Finally, CAD/CAM is now seen to play an increasing role in tool design, and Alcan has already taken this direction for its extrusion tooling, a trend that competitors and other non-ferrous metals fabricating industries are most likely to follow.

(A) Aluminum

Getting most out of present fabricating facilities (i.e. increasing productivity, etc) is clearly the first priority amongst Canadian non-ferrous metals fabricating industries. Specifically, however, the Aluminum industry strives towards improved fuel economy in its melting and annealing operations. Next to it comes material utilization, particularly in handling molten metal ("marinite", filtering media, etc). Then comes tooling, both from the point of view of design and longevity. Computerized automation and control remains an essential longer term objective.

As it is well known, a major current thrust within the Aluminum industry (particularly Reynolds) is recycling: this again relates to energy saving since the remelting cost is so much lower than the energy cost required to produce primary aluminum. One ensuing technological requirement is in the control of iron and manganese, although this probably falls short of PMRL/CANMET's preoccupations with respect to non-ferrous metals fabricating (?).

Apart from the clearly expressed needs related to energy (23-25), topics of a metallurgical nature for which short

to medium term solutions are sought include: (a) improved cost-effective material for handling molten metal (as a substitute for "marinite"), (b) inert gas (nitrogen) shrouding technique in the close vicinity of extrusion dies, (c) optimization of certain alloy extrusions in terms of productivity and product quality, (d) evaluation of tooling for extrusion (audit of current materials performance, exploration of improved materials, etc).

Examples of Alcan's major R&D thrusts include (26): (a) continued efforts in continuous strip casting, (b) extrusion press automation, (c) lubrication in cold-rolling, (d) alloy optimization in general, and from all points of view (composition, microstructure, etc) for maximum overall properties and performance. Again, energy savings remain a focal point in all areas of fabrication.

Federal support in the above areas should possibly concentrate on the more fundamental aspects in view of (a) the competitive nature of the aluminum fabricating business, and (b) the significant in-house R&D capabilities, particularly within Alcan: with regard to the latter, the contractor was told (26) that a collaborative effort was attempted a few years ago on the subject of automotive strip applications, and that things did not quite materialize for reasons of personnel availability. Clearly, a fresher approach is warranted.

(B) Copper

For reasons of productivity and product quality, static (water-cooled copper mould) casting of rolling slabs and extrusion billets of copper and its alloys is doomed! Therefore, with the exception of very special situations, semi-continuous and fully continuous casting processes do point the way the industry must go. Noranda, for instance, has already taken that direction. Now, then, opportunities exist for a better understanding of mould-metal reactions (gas-metal solubilities, etc), although in the case of graphite moulds, much improvements have come about in quality and reliability from graphite producers. Novel mould or mould coating materials or techniques still present interesting challenges for improved performance. Semi-continuous or fully continuous casting processes have not yet eliminated inverse segregation problems in certain alloys (eg, high tin, high phosphorous phosphor bronzes). Thus, electromagnetic casting, initially developed in USSR for aluminum and its alloys, would be worth examining.

In view of the trends in larger unit weights (longer billets) and thinner wall tubing (for increased length per unit weight), etc, lubrication, and concentricity of hollows, for instance, have become increasingly important to control. Also, along

with the recent advent of water-quenching at the press, namely for grain size control as well as for better microstructural control of certain alloys (eg, α-β brasses), tool performance has become a major factor in extrusion press productivity and product quality. Thus, there are opportunities for better tool materials (die, mandrel, liner), better methods of ensuring tube concentricity, and means of measuring the latter. Also, there might be advantages in studying the merit of gaseous media (as opposed to water) at the exit of the extrusion press.

In drawing, material transfer is an important issue, pretty well up to equipment manufacturers who have solutions (eg, spinner block, etc). However, here again tooling provides opportunities, from a material point of view, although to a lesser extent than for extrusion. This aspect is further emphasized in the pilgering (incremental deformation) process where maintenance costs are very high (this being the case at the Noranda Metal Industries' Special Metals Division, in Arnprior, Ontario, for high nickel alloys and stainless steels - Noranda's recent agreement with Sandvik).

In rolling, world-wide industrial problems remain shape control ans surface finish. Associated problems such as staining and sticking or welding during annealing call for a better under-

standing of metal-lubricant interaction and control of annealing furnace atmosphere.

(D) Lead

New lead and lead alloy fabrication technologies are almost impossible to predict unless entirely novel markets opportunities occur. The metal (and its known alloys) are easily amenable to warm and cold deformation processes, and adaptation of current fabrication know-how would eventually be technically quite feasible, etc. In summary, no particular technological barrier would appear as with the higher-melting point metals.

(E) Magnesium

It is obvious that the greatest challenge facing the future of the magnesium fabricating industry, particularly extrusion products, is a breakthrough in primary processing (reduction process) so as to bring the metal processing cost down and, therefore, the metal price!

In the meantime, however, Chromasco Ltd, in Canada, is working towards increasing extrusion productivity, with proper modifications to its present equipment, eg, larger container for increased extrusion ratio, etc.

Another overall industry objective relates to the development of relatively economical surface treatments, so as to improve generally the corrosion resistance of magnesium and its alloys. Furthermore, it is the writer's view that much improvement can be brought about in the casting of extrusion billets: this topic is, in itself, a golden opportunity for PMRL/CANMET (elimination of surface defects, thus billet machining, increasing casting speed, etc).

(F) Nickel

The Canadian technology currently employed for the fabrication of coinage strip is certainly unique. There is, clearly, excess capacity, and new market opportunities, say, for nickel alloys, could require process modifications, thus, increased R&D, if not solely development.

Semi-continuous of fully continuous casting, extrusion, and drawing of high-nickel alloys may require further development: here again, market opportunities ("pull" vs "push") should preside. One such opportunity resides in the most economical route for the fabrication of nickel and nickel alloy rod or wire: rod casting with or without subsequent rod rolling and drawing.

Forging and/or hot-hydrostatic pressing of special alloys, say, for aeronautical applications, provides an area for future development in Canada. However, as mentionned earlier, such development (...and research) most probably belongs with NAE of NRCC, in close collaboration with potential Canadian manufacturers and users.

(G) Zinc

Attempting to address furture technological prospects for wrought zinc alloys may be regarded almost as an exercise in futility! And yet, the writer for one, still feels strongly that the last word has not been said about the market potential and, specifically, the appropriate segment of the market that these alloys can share, particularly the lighter near-eutectoid zinc-aluminum alloys. Clearly, market "push" has been exercised; now, market "pull" is required, and it is only in these terms that one can dare think in terms of future technological prospects. Thus, a missionary type of approach is warranted: on the one hand, market probing (based on available technical information) must be agressively, but intelligently, pursued, and on the other hand, processing options must be evaluated, eg, billet casting and extrusion versus rod casting, in terms of costs as well as production reliability and performance, etc.

The commercial avenues that appear possible are: (a) rod wire for metallizing, (b) superplastic Zn-Al thermoforming and (c) Zn-Al screw-machining and bearing (rod) applications. With regard to (a) above, a choice amongst several technologies would address to a relatively small market (about 200 tons per year). Item (b) seems to be loosing ground to developing aluminum superplastic alloys, although COMINCO is still confident that near-eutectoid Zn-Al alloys have a place on a market which

has yet to be conquered (20). Finally, with regard to item (c) above, it is believed (19) that the Canadian technology in this regard will come to commercial fruition as a result of, or following, successful market penetration of the very promising foundry alloys which have, in fact, resulted from the effort on wrought alloys technical developments.

5. OPPORTUNITIES FOR ENHANCED GOVERNMENTAL R&D (CANMET)

This chapter reflects needs as expressed by contacted parties, literature providing also interesting suggestions which, however, may not relate to the Canadian context, etc.

Here, instead of proceeding by metals, as in the previous chapters, an attempt will be made to outline R&D opportunities from a run down of non-ferrous metals fabricating steps, from casting down to finishing (semi-fabricated products).

(A) Melting and casting

- an energy audit of melting practices (mode of heating, etc) on a basis of heat input per metal throughput
- cost-effective molten metal handling materials (eg. "marinite" in the case of aluminum: Reynolds is currently experimenting with a lighter, more durable, ceramic-base material, etc) and a substitution for graphite for copper alloys (...zinc and nickel bearing...) in continuous strip casting
- optimization of DC billet casting of magnesium and its alloys: linear casting speeds are low, surface finish needs to be improved (castings are machined all-over), etc
- means of minimizing or eliminating inverse segregation at the surface of certain alloys eg. phosphor bronzes (tin bearing copper), certain aluminum alloys such as titanium bearing 5003, etc: in this regard, electromagnetic casting could be examined
- means of continuous casting small magnesium and magnesium alloys directly, as an alternative to extrusion, and also of nickel rod as a means of bypassing rod rolling

(B) Hot deformation (rolling and extrusion)

- optimization of hot-rolling schedule of certain aluminum alloys (...through contacts with appropriate company, eg, Reynolds)
- optimization of extrusion parameters and overall practice (increased throughput) of certain non-ferrous metals and alloys (...through contacts with appropriate companies, eg, Chromasco, Noranda, Reynolds)
- a materials audit for tooling (liners, dies, etc), and a possible development program for improved materials, eg, metal or ceramic-based, etc (...through contacts with appropriate companies)

(C) Cold deformation (rolling, drawing, pilgering, etc)

- optimization of cold-rolling schedule, particularly from the point of view of lubrication (...its effect on staining and sticking during or as a result of post heat-treatment, specially of copper...), and also from the point of view of shape control (...effect of roll camber, tension, etc) for aluminum, copper and their alloys
- Note: other aspects would probably be less rewarding with the notable exception of pilgering (practised by Noranda Metal Industries Ltd at its Arnprior plant) where maintenance costs present a substantial challenge (...lubrication, die material, stroke, etc...)

(D) Miscellaneous

- instrumentation for fabricating process control and product quality evaluation (preferably on-line) remains a major field for innovating R&D endeavours: the technological barriers therein are probably more surmountable than in the case of, say, steel where harsher environment prevails, etc. Typically,

needs do exist in the area of seamless pipe and tube fabrication (eccentricity) and welded tube (weld defect); application of existing (Alcan, Reynolds) shape and gage control devices to copper and copper alloy rolling (cold) should also be considered

- opportunities also exist for fundamental studies on casting and working of certain alloys of aluminum, copper and magnesium
- although not of an R&D nature, fabrication and/or certification of alloy standards for, say, spectroscopic analysis has also been mentioned by Reynolds and Chromasco spokesmen
- characterization of new products (wear, corrosion, fatigue, etc) and system performance evaluation should be considered.

NOTE: willingness to collaborate with PMRL/CANMET has been mentioned by Reynolds' two plants visited, Chromasco, Wolverine and Noranda representatives; special interest in this regard was indicated by Sherritt Gordon.

The modalities of collaboration with the subject industry, and the priorities of execution of some of the above suggested R&D topics clearly rest with the direction of PMRL/CANMET. It is, however, the contractor's strong feeling that PMRL can best contribute to the overall non-ferrous metals fabricating industry in the areasof (a) continuous casting, (b) extrusion, (c) cold rolling, and (d) new product characterization and performance evaluation.

It has always been the contractor's contention that alloy development per se (as opposed to alloying techniques and strenghtening mechanisms) should not be the mandate of governmental nor

university research institutes: this is, clearly, the preserves of industry or at least the terrain where a winning alloy (with proper patent protection) can give a company a lead over its competitors, etc. This concept, however, may not necessarily be valid for metals which are used as alloying elements (eg, PMRL/CANMET's past program on the potential application of uranium as an alloying element...).

It is suggested that a PERSON within PMRL/CANMET be endowed with the responsibility of interfacing with the subject industry, so that both parties can come to grips with the appropriate issues, define areas of complementary R&D efforts, and insure that liaison is maintained. Naturally, experts in specific fields would develop and maintain their own technical contacts with industry, but a different level of communication, say, at the manager position, can best ascertain pertinence, timing and deliverables, etc, in the best interest of Canada.

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7. APPENDICES

(A) Organizations and people contacted

20 July — International Nickel Company of Canada Ltd (INCO), Toronto: phone conversation
W. Brokenshire, sales

21 July — International Nickel Company of Canada Ltd (INCO), Toronto: phone conversation
K. McPhail, general manager, sales

23 July — Canadian Copper and Brass Development Association (CCBDA), Toronto: visited
A.A. Knapp, technical director
R. Wardell, executive director

Product Research Centre (COMINCO), Mississauga:
J. Lewis, director, visited

27 July — Industry Trade and Commerce Canada, Ottawa: visited
D. Peplinski, non-ferrous metals and fabricating
W.E. Bessant (aluminum)
P.A. Jeffreys (powder metallurgy)
S.S. Petrash (copper and brass, magnesium)

28 July — Noranda Metal Industries Ltd (NMI), Montreal-East: phone conversation
M. Vachon, metallurgical services

29 July — Wolverine Division, UOP Ltd, London: visited
R. Stotts, director of engineering

2 August — Noranda Research Centre, Pointe-Claire: visited
E. Gervais, head of product engineering division
J.C. Farge, head of physical metallurgy dept.

4 August — Chromasco Ltd, Toronto: phone conversation
G.H. Blouin, vice president

5 August — Noranda Metal Industries Ltd (NMI), Montreal-East: visited, W. Houle, process engineering

9 August	Société d'Aluminium Reynolds (Canada) Ltée, Cap-de-la-Madeleine: visited J. Marchildon, director, research and development, R. Lanneville, manager, quality control, R. Noel, plant manager, Y. Boisselle, manager, rolling mill
17 August	La Compagnie de Profilés Reynolds Ltée, Ste-Thérèse: visited G.G. Desnoyers, vice president
18 August	Noranda Sales Corporation Ltd, Toronto: phone conversation G.W. German, asst. vice president, lead and zinc metal
19 August	Chromasco Ltd, Haley: visited P.J. McCann, manager-operations A. Froats, chief metallurgist J.W. Scobie, superintendent processing
24 August	Physical Metallurgy Research Laboratories, Canada Centre for Mineral and Energy Technology, Ottawa: visited D.W.G. White, manager, metal development laboratory
27 August	Sherritt Gordon Mines Ltd, Forth Saskatchewan: phone conversation M. Clegg, manager, physical metallurgy
31 August	Noranda Research Centre, Pointe-Claire: visited E. Gervais, head of product engineering division
3 Sept.	Aluminum Company of Canada Ltd, Montreal: phone conversation P.A. Dougall, manager, raw materials technology
15 Sept.	Aluminum Laboratories Ltd, Kingston: phone conversation P.E. Fortin, physical metallurgist

(APPENDIX B)

FROM: P. Chollet

SUBJECT: Project N-737-6: A Critical Review of the Developing Technology in Metal Processing and Products - Progress Report

SUMMARY

A systematic review of technical, trade and patent literature has been started with a view to identifying new developments in metal manufacturing processes and products, particularly copper and aluminum alloys, which can be of interest to Noranda, and which may require a significant R&D component for commercialization. In this review, an attempt has also been made to identify areas for improvement in the more conventional processes such as those currently used by Noranda.

The review so far has indicated that: (a) the pendulum-type rolling mills are showing technical advantages and economical merits for batch production of some non-ferrous metal strip; (b) continuous drawing and high-speed, long-stroke cold pilgering are enjoying greater popularity for tube making, whereas increasing use of tube welding for thinner walls is forecast; (c) amongst the continuous processes for wire manufacture, Conform is the closest to commercial viability; (d) several new wrought copper and aluminum alloys for varying applications have emerged, but no real breakthrough is noted.

Opportunities do exist for further optimization of Noranda's metal fabrication processes, and some of the newer processes warrant a detailed assessment.

DETAILS

A systematic review of technical, trade and patent literature has been started with a view to identifying new developments in metal manufacturing processes and products, particularly copper and aluminum alloys, which can be of interest to Noranda, and which may require a significant R&D component for commercialization. Developments in the field of continuous casting are not covered, although the subject will be referred to since it may constitute a crucial element of a given total process; similarly, cast iron, steel and zinc product technologies are excluded from the review since they are the subject of on-going reviews under existing projects in the Product Engineering Division.

The present activity has commenced with a literature search covering the last two to five years, of the Noranda Patent Newsletter, the Copper Data Centre Bulletin (Patent Brief), Inside R&D, International Metals Reviews, Iron Age Metalworking International, Metals Technology, Metals and Materials, and others. Very pertinent review articles were found, along with specific articles not covered therein and, of course, dozens of relevant patents.

This first report gives a bird's-eye view of general trends, both in metal-working processes and in alloy development.

I. Metalworking Processes

An excellent review paper has recently been published(1) on bulk metal deformation processes such as rolling (hot and cold), tube making, forging and wire manufacture. Discussions of these

metalworking processes include theoretical, economic and production considerations, and they represent a fairly up-to-date account of advances and trends in development. The bibliography for the pertinent subjects is extensive: 104 references on rolling, 164 references on tube making and 326 references on wire manufacture. A few comments pertaining to the above review paper as well as others(²), and which again relate more specifically to the interest of Noranda are given below.

a) Rolling

Sparling (see ref. 1) has broadly divided R&D activities on metal rolling into four categories: (a) fundamental research, (b) remedial research for production, (c) data provision and (d) early stage development. Fundamental research is mainly concerned with the mechanisms of deformation of the metal in the roll gap and the derived quantities which affect the operation of rolling mills. Such quantities are roll separating force (or load), torque, and spread (or transverse strain). Remedial research for production stems from production difficulties which defy operators' attempts at their rectification. This type of research seldom results in generally applicable knowledge, but without such work, the production of defective material might reach alarming proportions. According to Sparling, research for data provision, such as data on resistance to deformation of metals for both hot and cold rolling and at various strain rates is urgently needed for a far wider range of metal compositions. Realistic, comparative data regarding wear of different roll materials, for different roll pass features and for various lubricants is a further example

of the many fields in which quantitative data will be required before further optimization and automation of the rolling process can be achieved. Finally, in the category of early stage development comes most research activities of rolling mill manufacturers.

From the viewpoint of pertinence to Noranda, it is believed that the most profitable type of R&D in the area of rolling is remedial research for production. Perhaps the most significant example is shape control. "Poor shape essentially results from variations in gauge across the width of a strip and is accentuated by wavy edges or centre buckle produced in earlier stages of rolling and by residual stresses...Annealing does little to eliminate the bad shape and may even aggravate poor shape by relieving residual stresses"[1]. Sheppard and Roberts[3] have treated in detail shape defects and their causes, control and remedies: their paper, therefore, provides a basic document for future studies.

In the area of new rolling concepts, the most spectacular development lies in the Pendulum Mill[1,4-6] due to Saxl of Imperial Metal Industries Ltd. and its off-shoot, the Cycloidal Mill[7], currently being developed by Josef Fröhling in West Germany. Briefly, the very large reduction of thickness (up to 90% in one pass) is achieved by an incremental rolling process. Two small freely rotating work rolls are moved backwards and forwards over short curved converging paths, while powerful feed rolls force the stock through the narrowing gap[5]. These processes are perfectly suited for batch production of non-ferrous metals using continuously cast strip as feed stock.

b) Tube Making

According to Blazynski (see ref. 1) current developments, from a theoretical point of view, are characterized by analytical approaches to the problem of establishing more realistic relations between the applied forces, torques, etc. and the resulting deformation, with a view to helping the plant designer and production line planner. A typical problem which is receiving growing attention is the rational design of tool profiles and therefore of the geometry of the pass.

Amongst new developments, hydrostatic extrusion is still making progress and techniques employing either fixed or floating mandrels have been developed namely by Battelle. In conventional extrusion, lubrication is the subject of systematic search, particularly with respect to non-ferrous metals. Pilgering as a means of cold reduction is enjoying greater popularity(⁸). A new shift toward lighter walls in tubular products in a drive for increased tube length per unit weight is forecast(⁹): This calls for increased use of tube welding, as exemplified (and practiced on a large scale) by Anaconda(⁹) and Olin Brass(¹⁰).

c) Rod and Wire

Here again, two avenues of approach are being pursued; improvements or advances in conventional drawing, and development of new manufacturing processes. Rowe (see ref. 1) clearly recognizes the importance of incorporating theoretical analyses of plastic deformation in a general systems approach to the total wire production process. Rowe summarizes the many solutions that

have been proposed for improved drawing efficiency and product quality, and some of them could be applied to Noranda's practices if and when deemed necessary. One specific solution which may be considered intermediate between process optimization and adaptation of a new concept is the combined shaving/swaging of continuous cast rod proposed by Cochrane([11,12]).

In the area of new concepts, the last five years or so have seen many interesting developments aimed at either improving lubrication, decreasing forces or increasing draft (reduction per pass). Continuous hydrostatic extrusion with its attendant high unit reductions has made significant advances but few units are commercially employed. Perhaps the most significant developments are Green's hydrospin or helical (semi-continuous) extrusion process, Fuch's hydrostatic extrusion processes, Green's Conform and the related Linex process, and Avitzur's Extrolling process ([1,2]). Of these various approaches, however, Conform is probably the closest to commercial viability. Shaw's concept [13]), based on metal cutting, does not seem to have progressed very far.

2. Alloy Development

Alloy development is generally carried out by large metal producers and, also, by high technology corporations and service industries (Bell, IBM, GE, etc.). A review of the patent literature for the last two years has shown that Olin Corporation in the U.S.A. dominates by far in the development of new copper alloys, whereas the Japanese, Sumitomo in particular, lead in the area of aluminum alloy development followed, in the western world, by Swiss Aluminum Ltd. The bulk of patents on aluminum alloys

relates to electrical conductor applications whereas in the case of copper, the field of application is much wider, covering tubes for heat exchangers, spring for relays, electrical conductors, etc.

Bradley([14]) has reviewed developments in copper-base alloys for marine applications, and Cronin([15]) has summarized the properties of copper alloys for high temperature applications. With regard to the former, one of INCRA's significant efforts([16]), although not an alloy development per se, is in the application of cupro-nickel as a steel cladding for ship hulls. INCRA([16]) is also providing basic data in the area of elevated temperature performance of wrought copper alloys.

A good review of the extruded aluminum alloys has been made by Develay of Pechiney Aluminum([17]). Recent aluminum alloy developments in the competitive field of automotive applications, particularly for plate and sheet, have been reviewed by Deschamps et al([18]) and Rouanet([19]) in France, and by Baxter([20]) in the U.S.A. Trends in the use of new copper and aluminum alloys were recently given by Chandler and Baxter([21]).

3. Discussion

a) Alloys vs Process

As a general comment, it may be said that wrought alloy development would probably be less rewarding for Noranda Manufacturing Companies than, say, process improvements or the development of new process technology. By contrast, a foundry (cast) alloy requires far less processing steps and the chance of success and the development time are more favorable than in the case of a

wrought alloy. Thus, it is believed that the Research Centre could best serve the interests of the Noranda Manufacturing Companies such as NMI, NORAL and CWC by concentrating on existing manufacturing processes or steps requiring further optimization and on adapting novel concepts to current products. With particular reference to NMI, however, the above considerations do not negate the merit nor the opportunity of a proprietary position in a specific product line; a case in point may be calcium-deoxidized copper for welded tube application which the Research Centre developed to an incomplete state([22,23]).

b) Metallurgical Process Optimization

Significant improvements in process efficiency and product quality may frequently be realized through optimization of some of the equipment variables and operating conditions. Marginal improvements, however, may result because of an oversight of the total production process. The old saying "There is no cure for a sick ingot" is not entirely irrelevant in the present context; surface quality, soundness and structural homogeneity of the original casting will influence the significance of process optimization at least as far as the quality of the final product is concerned. Table I shows some of the approaches that may be considered, in the Noranda context, in terms of process optimization. Some of the topics could provide a good basis for joint collaboration between plant personnel and the Research Centre. In fact, two specific instances have indeed been the object of fruitful teamwork: phosphor bronze and other alloy rod drawing optimization

at NMI, Montreal East, and optimization of ageing characteristics of aluminum alloy 6063 at Norandex.

c) Novel Metalworking Concepts

Some of the newer metal fabrication processes are listed in Table II. Some of them have reached commercialization, e.g. tube welding, whereas others such as Extrolling are still at the technical feasibility stage. The significance of these various processes will depend on whether the highest quality product can be obtained at the lowest cost, and this will also have to take into consideration their flexibility and output. It is therefore essential that these various processes be costed on the basis of their expected or demonstrated potential, but consideration should also be given to fully assessing the technical advantages. It is worth mentioning that one such economic assessment has been published([24]); it relates to a comparison of the cost of producing soft copper wire, aluminum bronze welding rod and copper conductor strip by the Conform process and by conventional processing.

d) Plant Design and Automation

Another approach exists to metal fabrication which is more specifically aimed at the global improvement of plant productivity. Clearly, consideration of plant design, automation, more efficient production machinery, better scrap utilization and better yield, say, via more rational foundry practices (processing larger unit weights), etc., should be regarded at least as complementary to metallurgical process optimization. R.J.B. Molson([25]) has recently

touched upon this with regard to tube making at NMI, Montreal East. This subject has also been dealt with by Osman([24]) with regard to wire manufacturing. The advantages of continuous bull blocks (or spinner blocks) for tube production which Molson([25]) has referred to, and some of the recent developments in tube processing equipment and automation are briefly discussed in Reference 8.

FUTURE WORK

1. The review of recent advances in metal fabrication processes of interest to Noranda will be completed.
2. Contacts will be established with technical personnel involved in some of the developing technologies and visits will be made if deemed necessary.
3. Specific recommendations will be made for detailed assessment of promising new technology which can benefit Noranda's manufacturing operations.

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TABLE I

PRELIMINARY (QUALITATIVE) CONSIDERATIONS OF REQUIREMENTS FOR OPTIMIZATION OF NORANDA'S METAL FABRICATION PROCESSES

PROCESS \ OBJECTIVE	Increased Reduction per pass, reduced Forces and Die Wear	Thinner Gauge	Improved Product Appearance and Tolerance	Improved Product Properties	Increased Productivity
Rolling	- Marginally feasible with present equipment.	- Certainly possible with high quality castings.	- May warrant a study of pass design, tension control, roll camber for improved strip and sheet shape. - Control of lubrication and annealing atmosphere. - High quality castings.	-High quality castings. - Temper annealing vs temper rolling.	- Overall plant design and automation.
Tube Making	- Ensure use of proper tool geometry and mode of lubrication. - Use of ultrasonics, e.g. plug excitation**	- Optimization of extrusion and/or drawing tool	- Control of extrusion and drawing tool geometry. - High quality castings and/or extrusions.	- High quality castings.	- Overall plant design and automation.
Special Shapes*	- Marginally feasible with present equipment.	- - -	- Control of extrusion conditions and tool geometry.	- Control of solutioning heat treatment, extrusion temperature and ageing cycle.	- Overall plant design and automation.
Rod & Wire Manufacture	- Ensure use of proper die geometry, lubricant and interanneal conditions (time and temperature).	- - -	- Control of die geometry (land length), lubrication cooling and cleaning, annealing atmosphere. - High quality castings and/or extrusions.	- High quality castings.	- Overall plant design and automation.

* Applies specifically to Noranda aluminum extrusions. ** A non-conventional technique rather than a process optimization step.

TABLE II

SOME OF THE NEWER METAL FABRICATION PROCESSES THAT MAY HAVE A SIGNIFICANT IMPACT ON NORANDA'S FUTURE PROFITABILITY

PRODUCT LINE	PROCESS	MAIN TECHNICAL (OR OTHER) ADVANTAGE	SUITABILITY	STATUS
STRIP	- Pendulum mill	- Large reduction per pass	- Small batch production of a range of materials from continuously cast strip.	- Prototype production, namely of phosphor bronze, brass, nickel-silver and plain carbon steel.
	- Cycloidal mill			
TUBE	- Tube welding from strip	- Thin gauge tubing	- Cu alloys, Ti	- A commercial reality
	- Hydrostatic extrusion	- Large reduction per pass	- Cu, Al, bimetallics	- Restricted commercial use
	- Unclad extrusion	- Lower cost, higher quality product	- Reactive metals (Zr, Ti)	- Restricted commercial use and on-going (Noranda) small scale development
	- Conform	-	-	- Developmental
	- High speed cold pilger mill	- Large cross-section and wall reductions	- Ferrous and non-ferrous metals	- In use.
ROD & WIRE	- High pressure lubrication drawing	- Large reduction per pass	- Hard-to-draw alloys requiring several inter-anneals	- Some concepts in use, and shelved (Noranda) development
	- Semi-continuous (hydrospin) and continuous (Fuchs' process) extrusion	- Large reduction ratio	- Cu, Al, wire, strip and special shapes	- Developmental
	- Conform (cont. extrusion)	- Large reduction ratio; can use metal powders as feed stock	- Cu, Al, etc., in line with small section cont. casting machines	- Restricted commercial use; still being perfected
	- Linex (cont. extrusion)	- Large reduction ratio; uses strip as feed stock	- idem	- Restricted commercial use; still being perfected
	- Extrolling (rolling & cont. extrusion)	- idem	- idem	- Small-scale developmental.